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ABSTRACT

The 1983-84 annual report of the President of Harvard University to members of the Board of Overseers addresses the advantages and disadvantages of the utilization of new technologies by a university, comments on the instructional uses of computers (including computer assisted instruction (CAI)) and video technology, and cites specific examples in which Harvard has adopted such instructional methods. Examples include simulated environments in the Medical, Law, and Business Schools, use of CAI instruction in bookkeeping and accounting classes in the Business School, and use of closed circuit television to link the Medical School to teaching hospitals and other Boston institutions. Also discussed are possible future uses of technology at Harvard such as videodisc applications for art history and links betweeen student microcomputers and the library's online catalog. Some objections to the new technology are also discussed, including speculation on the computer's inability to contribute much to the "open-ended" fields of moral philosophy, religion, historical interpretation, literary criticism, or social theory, and its failure to inspire students or serve as a role model. It is argued that humanistic learning has suffered from "ill-considered" efforts to ape the scientists by concentrating on what is quantifiable, verifiable, and value free. More attention to the process by which students learn is called for, and the possibility that technology may inadvertently assist that endeavor is noted. New technologies are welcomed with "cautious enthusiasm," and it is suggested that the new machines may be a catalyst to hasten the development of new insights into human cognition and new ways of helping students to learn. (JB)

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HARVARD UNIVERSITY

THE PRESIDENT's REPORT

1983-84

Derek Bok

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TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

To the Members of the Board of Overseers:

Ladies and Gentlemen, I have the honor to present my report for 1983-84.

During the past year, universities have begun to attract a new kind of publicity. The most arresting stories to appear in our newspapers have not featured students, or professors, or even new curricula. They have focused on machines:

Hewlett-Packard Gives Five Million Dollar Grant for Computer Equipment to Harvard Medical School

Digital Plans $45 Million Education Project

A Personal Computer for Every Freshman: Even Faculty Skeptics Are Now Enthusiasts

All across the country, headlines like these have signaled the sudden rush of a new technology that promises to leave a lasting imprint on the practice of education at Harvard and other universities.

Technology is already starting to affect the way in which students prepare for classes in several of our professional schools. Last fall, the Business School began requiring every entering student to purchase an IBM personal computer. Those who were unfamiliar with these machines received special instruction in their use. Software was distributed to enable students to manipulate financial data. Word processing programs were provided to assist students in preparing their reports. Because of the formidable powers of the personal computer, teachers could assign more complicated problems than before, problems that more closely resembled situations confronting corporate executives in real life.

The Law School has not yet required students to buy computers. But students and professors have formed an alliance to develop programs to help in mastering basic material such as the rules of accounting, tax, property, and evidence. Although these exercises are optional, over half the class has used them in some large courses. A more venturesome creation permits students to watch a mock trial on a screen and object at any point to the questions asked of witnesses. With each objection, a computer asks students to choose the ground for intervening from a list of possible reasons. If the student answers correctly, the computer so states and the trial resumes. If the student gives the wrong answer—or if there is no proper ground for protest—the computer so indicates and explains why the student erred. At the end of the tape, the program automatically flashes back to every point in the testimony at which the student failed to make a valid objection.

In the Medical School, computer programs have been developed to simulate patients with a variety of diseases. With these programs, students can ask the "patient" questions or order medical tests, and plausible answers or test results will instantly appear on the screen. By framing hypotheses and testing them in this fashion, students can eventually make a diagnosis and either have it confirmed or ask the computer where their reasoning went astray.

More conventional video technology is already in wide use to carry instruction to students at separate geographical locations. At Harvard, the Medical School is connected by closed-circuit TV to our teaching hospitals, to the Science Center in Cambridge, to MIT and even to other, more distant institutions via satellite. Through these links, speeches and seminars at any of these institutions can be viewed by faculty and students in all the others. Elsewhere, universities have launched even more ambitious ventures. Stanford offers engineering courses by closed-circuit TV so that employees in high-tech companies throughout Silicon Valley can attend class without leaving their place of work. The University of Washington gives televised courses to supplement the education of medical students in places as distant as Alaska, Idaho, and Montana.

Technology also offers ways of improving communication outside of class among people in different locations. By linking personal computers to one another, a university can enable students to send messages back and forth and ask questions of instructors or campus officials. In this way, students can seek help from many classmates simultaneously and communicate with less inhibition and greater ease with their professors.

Libraries provide another fertile place for technological innovation. By next July, almost all of our new acquisitions will be registered in a computer so that librarians can instantly learn the whereabouts of a recent book or periodical, not only in our own collections but in any of a number of cooperating institutions.* Medical students will soon be able to use their personal computers to search for articles in a number of journals and instantly reproduce the entire text. It is not yet possible to do the same for all books and articles in a library, since most of these materials do not exist in machine-readable form. In the not-too-distant future, however, computers may be able to conjure up on a screen the titles, tables of contents, and indexes not only of all books in a university library but of all volumes in all participating libraries across the country and abroad.

Prospects for the New Technology

In theory, at least, the new technology has the power to transform the nature of the university. Much routine advising could shift to a network of personal computers linked to a common data base so that students could instantly have the answers to a host of factual questions about course requirements, employment interviews, campus events, and homework assignments. In time, lectures could move from classrooms to television screens so that students could listen to a professor and immediately test their comprehension of the material by working through a series of questions and problems presented by an appropriate computer program. Science concentrators could simulate many laboratory experiments on computers without leaving their residence hall. Video technology could not only transmit lectures but bring the resources of the outside world to students in living color. For example, art history majors could use a videodisc linked with a computer to explore the great museums of the world, examine the details of any painting they chose for as long as they wished, and summon up text to explain the picture and the circumstances under which it was painted.

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To begin with, although in principle most advantages of technology *can* be duplicated by conventional methods, the truth is that few of these advantages *will* be achieved without the new machines. Instructors could spend two hundred hours preparing for a traditional class just as they must often do to develop an hour of computer-assisted instruction. But rarely will they actually do so. Medical schools will not provide individual tutors patient enough to allow each student to practice endlessly developing diagnostic skills. Nor will distinguished specialists be available to explain to each medical student how they reason step-by-step to arrive at a diagnosis. With student-faculty ratios of 20 or 30 to 1, a law school professor cannot work with individual students to check their progress in understanding the Socratic dialogues in which they participate vicariously in class. Nor will science majors always have an opportunity to repeat difficult experiments in the laboratory as they can by performing them in simulated form on their computer. Even the humble word processor has advantages. Without it, as Richard Marius has said, students in Expository Writing will continue to revise by merely adding a word here and changing one there; they "can seldom be made to do the so-called global revisions that involve major shifts in the argument, the elimination of some material, and the introduction of new evidence and sometimes a new point of view."[10]

The opportunities that technology brings to life have great educational value. At present, most instruction in our universities is far too passive. Professors rely excessively on the lecture. Seminars are often consumed by dull recitations of student work. Discussion groups are typically led by graduate students who lack experience in teaching, especially by the discussion method. Granted, students are challenged to think for themselves in preparing for exams and writing papers. But all too often, exam grades come back with little or no explanation, while term papers return with only a few hastily scribbled comments.

As knowledge increases and methods of analysis grow more complex, it is less and less desirable to base education so heavily on the passive experience of listening to lectures and reading texts. Habits of critical thinking, of perceiving and solving problems, of deriving useful generalizations from bodies of data, all seem increasingly important and all require more active effort by the student. In the words of a recent report for the National Academy of Science, "Cognitive research confirms that knowledge learned without conceptual understanding or functional application to problems is either forgotten or remains inert when it is needed in situations that differ from ones in which the knowledge was acquired."[11] To the extent that new technology can offer a student challenging problems, opportunities for repeated practice in finding solutions, and possibilities for immediate feedback, it will provide exactly the kind of educational experiences most needed today in our universities.

Even if technology could not enhance the learning process, we can be reasonably sure that the graduates of most professional schools will need to work with computers—or at least understand their uses and limitations—in order to practice their calling in later life. With the waves of technical information that are engulfing medical practice, most physicians will have to use these machines to summon up the data they need and manipulate it to aid in reaching clinical decisions. Corporate executives already call on sophisticated computer analyses in reaching many business decisions. Even lawyers have come to rely on computers to do their research and may look to expert systems for help in making certain kinds of professional judgments. As the use of these machines continues to expand, therefore, it is the responsibility of most professional schools to familiarize their students with the technology and make them reasonably proficient in its use. Many of the computer applications we have discussed will have precisely this effect.

Thus far, therefore, the balance of benefits and risks seems to favor the new technology. There is yet another element that tilts the scales decisively in the same direction. Over the past twenty years, computers have proved to be a major stimulus for eliciting work and thought about teaching methods and the processes by which human beings learn. By their power and versatility, the new machines have given a stimulus to the field of cognitive psychology and turned the energies of many scientists toward artificial intelligence and its applications to learning. The significance of these developments for universities is greater than one might imagine.

A striking fact about higher education is the lack of systematic effort to understand the ways in which students learn. Faculties rarely spend time thinking collectively about the educational process. When they do, they almost always discuss *what* students should read and study rather than *how* students learn and how they might be helped to learn more effectively. It is as if automobile manufacturers never tried to figure out how their cars could be engineered to go faster, last longer, and achieve greater mileage. The reasons are not difficult to understand. Quite simply, no one is clamoring for more effective learning, while almost everyone has reasons for not caring to look too hard at the problem.

Neither alumni nor legislators try to exert much influence over the way in which faculties teach, and any effort on their part to do so would be resisted as an assault on academic freedom. Leaders in education are in a better position to make their wishes felt. Yet they continue to devote almost all their attention to arguing over what undergraduates should learn even though very few new ideas have emerged on this subject during the past thirty years. Witness the recent flurry of well-publicized reports on the state of the liberal arts, with their stale rhetoric and their shopworn arguments in behalf of familiar positions on curricular philosophy and design.

Students are also capable of exerting influence and are not bashful about asking many things of the university. They want a reasonable chance to pick and choose what courses to take; they want lively, informed teachers; they want opportunities for extracurricular activities; they want help in finding a good job. But they are not pressing for more effective instruction. Indeed, there is some evidence suggesting that the kinds of instruction students like best are not the most effective in helping them learn. These preferences are not deliberate or even conscious. Students simply have no way of knowing how much their intellectual skills and knowledge have grown, whether they might have developed faster at another institution, or what changes in instructional methods might help them to improve more rapidly.

These possibilities have fired the imagination of many observers. According to the president of Johns Hopkins, Steven Muller, "We are, whether fully conscious of it or not, already in an environment for higher education that represents the most drastic change since the founding of the University of Paris and Bologna . . . some eight or nine centuries ago."[1] Because of the speed and accuracy of the computer in performing computations and processing information, "what Ph.D.'s did 25 years ago will be term projects for Dartmouth students," according to Ray Neff, former director of computer services at Dartmouth.[2] "I'm not convinced that there will always be a book," says Frederick Kilgour in describing the electronic library of the future.[3] Adds Patrick Suppes, one of the pioneers in computerized instruction, "One can predict that in a few more years millions of [students] will have access to what Philip of Macedon's son Alexander enjoyed as a royal prerogative: the personal services of a tutor as well-informed and responsive as Aristotle."[4]

Amid this general euphoria, however, one can detect quieter, more skeptical voices. According to Richard Clark, a leader in evaluating the effects of educational technology: "Five decades of research suggest that there are no learning benefits to be gained from employing different media in instruction, regardless of their obviously attractive features or advertised superiority. . . . The best current evidence is that media are mere vehicles that deliver instruction but do not influence student achievement any more than the truck that delivers our groceries causes changes in our nutrition."[5]

Experience should also make us wary of dramatic claims for the impact of new technology. Thomas Edison was clearly wrong in declaring that the phonograph would revolutionize education. Radio could not make a lasting impact on the public schools even though foundations gave generous subsidies to bring programs into the classroom. Television met a similar fate in spite of glowing predictions heralding its powers to improve learning.

In each instance, technology failed to live up to its early promise for three reasons: resistance by teachers, high cost, and the absence of demonstrable gains in student achievement. There is as yet no clear evidence that computers and videodiscs will meet a happier fate. Faculty members may be as reluctant to give way to computers as they were in the case of radios and television sets. The cost of the equipment likewise remains quite formidable. According to one professor, to provide all of the 460,000 engineering students in America with a modern computer workstation joined by a network and linked to a central data base would cost ten billion dollars.[6] True, hardware costs have been declining at a compound rate of 25 percent for a number of years. But hardware makes up only a small fraction of the total cost of computer-assisted education; the major expense lies in preparing suitable materials and maintaining the software and the machines. Thus, the overall costs of the new technology seem likely to remain high for the foreseeable future.

Finally, the educational benefits of technology also remain in dispute. There is still little proof that new devices yield lasting improvements in learning. Many studies purport to find such gains. But most of them can be explained on the grounds that students using computers were temporarily motivated by the sheer novelty of the machines or that more effort and better teaching went into the computerized courses than were devoted to the conventional classes with which they were compared. Thus, the learning improvements that early investigators reported from computer-assisted instruction shrank to virtually nothing when the same teacher taught both the experimental and the conventional classes with comparable amounts of preparation. Similarly, the gains achieved in computer experiments lasting less than four weeks dropped by more than two-thirds when the experiments continued beyond eight weeks and the novelty of the new technology began to wear off.

Undaunted by these obstacles, educators and high tech companies are spending huge sums to prove the skeptics wrong. Control Data Corporation reputedly invested almost a billion dollars in the computerized college curriculum, PLATO. With assistance from major companies, Brown, MIT, Carnegie-Mellon, and other institutions are each spending tens of millions of dollars in equipment and programming to "wire" their campuses. Against the backdrop of these developments, Harvard's Faculty of Arts and Sciences has launched a comprehensive review of how technology might be best put to use for research, administrative, and, not least, educational purposes. It is high time that we studied these questions, for the computer revolution is already upon us. What impact might these machines have on the nature and effectiveness of education? What kinds of innovation are feasible and not prohibitively expensive? What advantages and disadvantages could technology bring to the quality of life in the University?

Machines that Eliminate Drudgery

Many widely used technological innovations seem principally designed to save time or eliminate drudgery and routine. Electronic bulletin boards spare students the burden of finding announcements in campus newspapers or dropping by departmental offices. On-line catalogues save a trip to the library reading room. Word processing avoids the trouble of typing new drafts, while remote-site TV can take away the need to travel from home to campus.

As these conveniences accumulate, one begins to wonder whether machines will eventually permit students to learn at home instead of going to the expense of living and attending courses on a university campus. If so, technology will not merely eliminate drudgery; it will save substantial sums by removing the need for dormitories, classroooms, and other costly facilities. The possibility is not entirely fanciful. After all, the Open University in Great Britain is enrolling 100,000 students in televised courses, and that achievement has come about without much use of microcomputers, videodiscs, and other newer devices that promise to expand the variety and challenge of instruction.

Despite the success of the Open University, the likelihood of

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*Other universities have already entered their entire collections into computers, a task that seems prohibitively expensive for Harvard with its more than ten million volumes. Current costs for translating catalogue cards to machine-readable form average $2 to $3 per card, and difficult items can run from $10 to $40 or even more.

depopulating our campuses through televised instruction seems remote. Residential universities offer compelling advantages. For many students, the opportunity for personal contact with faculty members is very important; think of the number of prominent graduates who point to a relationship or even a single encounter with a professor as a critical event in their college years. For most people, learning is also in part a group experience in which each student gains reinforcement from others. Thus, providers of televised learning, including the Open University, have found it necessary to offer tutorials, advising, periods of residency, and other devices that give more structure and human contact in order to sustain motivation. In addition, living with other young people and participating in extracurricular activities not only give pleasure; they contribute much to students' learning and to their tolerance for other points of view, their sense of responsibility, their social and emotional maturity. Apart from these benefits, the years spent living in a university afford to many people an enjoyable experience they would not willingly give up even to save a few thousand dollars a year in room and board. For all these reasons, the residential campus promises to remain a fixture despite its costs.

If the emancipating powers of technology will not do away with the residential university, will they lead to improvements in learning that go beyond mere convenience? It all depends on how students use the time technology saves them. In many cases, however, educational benefits will unquestionably occur. For example, the personal computer has not only enabled our Business School students to avoid drudgery; it has allowed them to grapple with more complicated, realistic problems, using linear programming and other sophisticated analytic techniques not previously feasible for ordinary homework assignments. In the Design School, computer-generated maps and models reduce the time and skill required to complete a drawing so that students can experiment with many more ways of solving landscape planning problems. In the College, word processing in experimental sections of Expository Writing has not merely spared students the drudgery of typing over papers; teachers can now ask students to revise and rewrite until they submit a more polished piece of work than would have been possible without the new machines. In all these cases, time previously spent doing dull, repetitive tasks can now be devoted to thinking about much more challenging, important questions.

Computer-Assisted Instruction

The new technology not only frees students from drudgery and routine; it often comes with software expressly designed to improve learning. One of the most common methods is called computer-assisted instruction (CAI). The intellectual origins of CAI go back to Thorndike's theory of stimulus-response and B. F. Skinner's development of teaching machines and programmed learning. According to Skinner, the aim of designing programmed learning was to construct a series of questions that almost every student could answer correctly. The act of giving the correct answer and the reinforcement that followed served to plant the knowledge more firmly in the student's mind.

The earliest computer-assisted instruction exemplified this method. The architects of CAI, however, soon broke with Skinner and sought to build programs that would be more challenging for the student. They stopped asking only questions that would elicit correct answers and began supplying text and helpful hints that would lead erring students to recognize their mistakes and figure out the correct answers. A simple example of such a program is the following:

Computer: Who was the first president of the United States?
(1) Thomas Jefferson
(2) George Washington
(3) Abraham Lincoln
Student: Abraham Lincoln
Computer: Sorry. Abraham Lincoln was President of the United States during the Civil War from 1861-65. The first President served from 1789 to 1797 and had previously been Commander-in-Chief of the Continental Army during the American Revolution. Would you like to try again?
Student: George Washington
Computer: Good work.

This basic format underlies much of the programming now in use to supplement classes in bookkeeping and accounting in the Business School and in a variety of Law School courses. In practice, of course, CAI can be much more sophisticated than the simple example given above. Some programs ask a few initial questions and, depending on the answers, branch automatically to material appropriate to the student's apparent level of ability and comprehension. Programs may also respond to wrong answers by taking the student back through the problem step-by-step to discover the source of error. Others take the form of games to motivate the student. For example, one French instructor at Harvard has used a program modeled on poker whereby teams are "dealt" questions and get points for giving correct answers.

Such exercises can help in several ways to supplement regular classwork. Students have to think and cannot merely read passively to take in information. They can practice when they wish and for as long as they wish. They can proceed as rapidly or as slowly as they please, moving on to new material only when they have mastered what has gone before. Well-crafted programs give students all the help and added explanation they need and automatically move to levels of difficulty appropriate to the learner. By instantly recording whether each response is correct or not, the computer allows students to recognize areas in which they need to do further work while alerting the instructor to problems that the entire class has encountered in mastering the material. In all these ways, the machine can adapt to the special needs of each individual and offer feedback of a kind rarely available in the conventional course.

Despite these advantages, CAI has obvious limitations. The programs are highly controlled in that the student must answer the precise question posed by the machine and choose among the limited number of responses appearing on the screen. There is no room in this format for challenging students to define the problem for themselves, explore a new hypothesis of their own, or speculate about the material under study. Because of these limitations, CAI is chiefly used to help learn facts, basic routines (as in mathematical computations), or collections of rules. In universities, the principal applications have involved tasks such as mastering foreign language vocabularies and grammar, or learning the rules of accounting, the elements of anatomy, and other bodies of basic information. In principle, students could do as well by conscientiously reading a printed text, supplemented by lists of questions at the end of each chapter. The hope is that computers will do the job better because they force each student to participate actively and master the material thoroughly in order to complete the program.

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Developing Higher Levels of Thinking

In recent times, more and more psychologists and educators have become interested in higher levels of thinking and thus have grown impatient with the limits of conventional CAI. Cognitive psychologists have turned from the earlier theories of stimulus-response to consider more complex ways in which knowledge and reasoning interact. In particular, they are exploring how the mind seems to process information by relating it to concepts that are constantly formed and adapted to assimilate new perceptions. Researchers are also trying to find how humans combine these concepts with reasoning skills to solve problems. According to recent investigators, one's ability to think can be improved in three different ways—by enlarging the stock of relevant information, by enhancing the conceptual structures through which one extracts more meaning from new pieces of information, and by improving one's heuristics or powers of reasoning. Influenced by this work, computer experts have been looking for ways of using technology to help students develop more complex skills of problem solving by learning how to form concepts and principles from information and experience and how to apply general principles to specific cases.

An obvious way to teach these skills is by the Socratic method, long a mainstay of law school classes. The proper Socratic teacher never gives answers but only asks questions. Through an artful choice of questions, students discover for themselves the inadequacies of their reasoning so that they can develop sounder generalizations and apply them to solve concrete problems. Could one program a computer to act as a Socratic teacher? After all, didn't Patrick Suppes promise us years ago that technology would soon give us "the personal services of a tutor as well-informed and responsive as Aristotle"?

In fact, the problem of training the computer to be a tutor has proved much more elusive than early enthusiasts assumed. One difficulty with most complicated subjects is that questions can often elicit so many answers that it is difficult to anticipate them all and provide for suitable responses in a program. Even if one could foresee all the answers, each would require a proper question in response that would in turn provoke a further profusion of answers, each requiring an appropriate question, and so on. The result is what experts call a "combinatorial explosion" that could exceed the capabilities of the programmer and even the computer itself.

A still more formidable problem arises from the fact that true dialogue requires each participant to interpret the responses of the other. At present, this talent lies well beyond the capacities of the machine. For one thing, the English language usually offers many ways to communicate the same idea. One can describe a home run by stating that "the ball sailed over the center-field wall" or "Jim blasted a round-tripper" or "the big first baseman muscled it out of the park." A computer would have to be programmed with more information than most machines can currently handle simply to interpret all the variations that can occur in conversing about most subjects. Worse yet, no one knows how to formulate a set of rules by which a computer can compare statements like these and recognize them as equivalents. A human being with adequate knowledge and experience perceives the similarities instantly. We simply do not understand how the process works.

These difficulties do not entirely rule out using computers as tutors. Some material is so structured that only a finite number of easily identifiable responses are possible. That is why a computer can be programmed to play a formidable game of checkers or even chess. Another possibility is to have the computer ask questions and require students to choose among a limited set of answers instead of allowing them to respond in any way they see fit. In this way, one can remove the problem of interpretation and reduce the combinatorial explosion to more manageable limits. Of course, resorting to multiple choices will significantly restrict the dialogue. One of the most important benefits of a Socratic exchange is to force students to think of their own responses instead of simply choosing from a predetermined list. Even so, a computerized dialogue using multiple choice could still encourage students to reason more carefully than they normally do with a traditional CAI program. The problem is to find instructors clever and dedicated enough to create software with responses to all of the answers that students can give even in this restricted form of mechanistic dialogue.

Another way of teaching higher-level reasoning comes from so-called expert systems. One of the best-known examples is MYCIN, a computer program that can rival specialists in diagnosing bacterial infections in the blood and prescribing appropriate treatments. The heart of the program consists of a few hundred rules that take the form: "If X is true, then ask the following question or take the following action." These rules in turn were created after long interviews with acknowledged experts to discover how they would go about making diagnoses and prescribing treatments. Physicians can use such systems as a check on their own clinical judgments. Armed with the MYCIN program, the computer asks questions about a patient, and the doctor answers with the appropriate data. The computer will continue to seek information until it is able to arrive at a conclusion which the doctor can compare with his own judgment.

Expert systems like MYCIN can be adapted for educational use. Students can not only observe how the "expert" goes about solving problems but can interrupt and ask the computer to explain the steps of its reasoning and why it reached a particular conclusion or asked a particular question. In this way, the computer permits students to have greater access to an experienced "mentor" and to question it in more detail than would normally be possible in real life.

Like all programs, expert systems have their limitations. They are expensive to produce. They do not force students to solve problems for themselves but merely ask them to supply data and observe how the computer responds. Above all, such systems work only for a limited range of problems in which the

knowledge involved is sufficiently structured, the possible relationships sufficiently finite, the inferences and conclusions sufficiently probable that programmers can deduce a series of rules with which to search for information, make and check hypotheses, and eventually reach a conclusion.

In making use of these devices, moreover, educators must remember that they are relying on a still unproven theory of how to teach problem solving. Cognitive research seems to indicate that specialists do not necessarily solve problems by the rational, step-by-step process embodied in expert systems. While they are capable of such analysis, specialists appear to function more intuitively. Instead of examining all the alternatives and methodically discarding the ones that do not fit, experts often seem to match the problem instinctively with a precept or pattern stored in their minds, adapting the pattern to the situation at hand in order to arrive at a solution. In teaching students to reason more systematically, educators assume that novices must first master the deliberate process and only then develop the expert's instincts and intuitive shortcuts as experience and knowledge accumulate. This assumption seems plausible; it underlies all instruction in problem solving whether or not the teacher makes use of technology. But it is still only an assumption and could conceivably turn out to be incorrect.

Some of these difficulties can be mitigated by yet another technological application. Recall the computer programs that simulate a patient and permit medical students to ask questions and order tests in an effort to diagnose the illness. With such a program, the role of the machine is entirely different. The computer does not ask questions or control the dialogue; it simply acts as a repository of information, a simulation of reality that students can explore and analyze in order to define a problem, develop and test hypotheses, and ultimately arrive at a reasoned solution. If an expert system is added to the program, a student who gets stymied can ask for help at any point, and the computer will indicate what information the student should seek and why in light of what is already known. Further commands will lead the computer to summon detailed information on any aspect of the problem that arouses the student's interest.

Exercises such as the simulated patient are a powerful tool for medical education. This is particularly true in an era when doctors must learn not only to make more complicated diagnoses using a growing array of tools but also to conduct their examinations at minimal cost by avoiding unnecessary tests and procedures. Of course, simulated exercises require some simplification to reduce the countless variations of real life to a model suitable for programming. Computer programs are also incapable of capturing the wisdom and compassion of a first-rate doctor responding to a patient's problems, questions, and anxieties. These limitations are enough to keep machines from replacing medical rounds, where students can observe doctors treating real patients on the hospital wards. Even so, as a supplement and preparation for such training, simulated patients should play a very useful role.

Simulations, using videodisc or simply computers, can have many other applications. They can teach law students to interview witnesses, help business school students learn to diagnose a company's marketing problems and recommend solutions, or even offer a graduate student a wealth of data with which to practice constructing a research design to test hypotheses about social behavior. The strength of these programs again lies in the challenge they pose for students to think for themselves to define the problem and reason toward a solution.

Other programs can simulate environments that are either too dangerous, too expensive, or too remote and inaccessible for humans to encounter directly. For example, with the help of computer graphics, undergraduates can observe the path of the moon circling the earth and conjure up changes in the mass or velocity of the moon in order to observe the effects of gravity on the shape of its orbit. Chemistry students can conduct simulated experiments on their TV screens combining substances too dangerous for laboratory use. Biology majors can watch simulated fruit flies breed at an accelerated pace and try to deduce genetic rules from the results. Medical students can observe the workings of the circulatory system and see how the removal of blood or the cutting of the nerve regulating blood pressure affects the functioning of the entire system. In all these cases, students have opportunities to visualize phenomena that they encounter ordinarily only in abstract form. They can also manipulate variables and observe their effects in ways that help them gain a more thorough understanding of concepts and processes that would otherwise seem remote and hard to understand.

A final use of simulated environments takes the form of elaborate computerized games in which students play different roles in competition with one another. In a business school contest, teams of students play the part of executives from different companies. In a city planning game, the teams represent political officials, planners, and business and community groups. In each case the students develop strategies and make decisions. The computer has a vast store of information based on actual experience in situations similar to those confronting the players. With these data, the computer can allow participants to observe the consequences that flow from their decisions so that they can adjust their strategies accordingly and act again. Games of this sort are generally used at the end of a course, not to teach new material, but to motivate students to integrate what they have already learned by bringing their knowledge to bear on a lifelike situation with the added spur of competing against their peers.

All of the applications I have described are simply illustrations of what is currently feasible in a rapidly changing field. If a cheap optical scanning device became available, students and faculty could soon conjure up on their TV screens virtually any book in the university library, or indeed in any participating library. If improved authoring systems were devised, instructors could prepare better software with much less effort, and the quantity and quality of computerized material would probably rise substantially. If we could understand the art of dialogue better, teachers might program the computer to conduct more challenging discussions with students. No one knows when or even whether these developments will occur. The one thing that does seem certain is that new applications will emerge tomorrow which no one can foresee today.

Now that we have looked at a sample of ingenious and arresting applications, it is time to examine these developments with a cold and skeptical eye. Apart from the excitement of the new machines, what is it, exactly, that they can do to improve the process of learning? What effects will they have on the campus environment?

The first point to remember is that many important tasks remain beyond the reach of the new technology. With all its powers, the computer cannot contribute much to the learning of open-ended subjects like moral philosophy, religion, historical interpretation, literary criticism, or social theory—fields of knowledge that cannot be reduced to formal rules and procedures. Since such subjects are among the most important in the curriculum, this limitation is hardly trivial. Computers are also incapable of inspiring students or serving as role models. They cannot conduct a genuine dialogue because they cannot comprehend analogies or metaphors or even understand conversation beyond the five-year-old level. Finally, machines can rarely tell why a student is experiencing difficulty in learning and understanding (although computers can test students and keep detailed records of their mistakes in order to help the teacher detect learning problems).

Whereas these limitations are important, they still leave ample room for applying technology to learning, especially in the major professional schools, in science departments, in engineering programs, and in many areas of social science. Other criticisms of technology, however, are more sweeping. They warn that computers may harm the entire educational process by gradually eroding some of the intangible, more humane values of university life.

A familiar concern of this kind is that computers may erect barriers that will isolate students and divide teachers from learners. If students have to spend more time with their new machines, they may become more solitary and avoid the human contact that does so much to enrich the university experience. If it really takes one hundred or two hundred hours to prepare a good program suitable for an hour's instruction, professors may withdraw to develop software leaving students to work alone at their consoles. There is also a risk of overlooking subtler benefits that come from older, less "efficient" methods of education. Lectures may be passive, but as the early devotees of self-paced instruction soon discovered, they can have an inspirational value, not replicable by machines, in showing what it means to be truly in command of an important subject. Answering student questions via computer may be more efficient, but posing a routine question to an advisor is often the way by which a shy student reaches out for help in dealing with homesickness, insecurity, and other problems to which no electronic device can possibly respond.

We also know that computers can have an unwholesome, almost addictive effect on some individuals. To borrow Joseph Weizenbaum's vivid description:

> Whenever computer centers have become established . . . bright young men of disheveled appearance, often with sunken glowing eyes, can be seen at computer consoles. . . . Their rumpled clothes, their unwashed and unshaven faces, and their uncombed hair all testify that they are oblivious to their bodies and to the world in which they live. They exist, at least when so engaged, only through and for computers. These are computer bums, compulsive programmers. They are an international phenomenon.[7]

Just what produces such behavior is not entirely clear. Sherry Turkle may come closest to the mark in describing such students as persons who do not get along easily with others and look upon the computer as a companion without emotional demands or human meanness, "a compromise between loneliness and fear of intimacy."[8] Whatever the explanation, such a fate is hardly what parents have in mind in paying many thousands of dollars a year to send their children to college.

A final concern is that computers may cause faculties to place too much emphasis on material that can be programmed while paying less and less attention to matters that are qualitative, speculative, and not reducible to formal rules and algorithms. Humanistic learning has suffered enough from ill-considered efforts to ape the scientists by concentrating on what is quantifiable, verifiable, and value-free. The seductive power of the new machines and their fascination for many students may only make matters worse. Do we not have a foretaste of things to come in the eagerness with which classicists fall upon computers for the analysis of ancient texts and the glee with which music instructors talk about teaching composition by machine?

Although these dangers are real, some seem exaggerated while the others are avoidable given a will to do so. For example, there is no reason to conclude that computers must diminish contact between students and faculty. Virtually all of the illustrations of technology discussed in this report supplement the lecture and seminar and do not replace the instructor. Where overlap occurs, the computer replaces the least rewarding tasks of a teacher, the recitation of basic concepts and information. The contacts that students like best—the give-and-take of the seminar, the conversation of a tutorial, the Socratic discussion of a complex problem—are the very tasks the computer cannot perform effectively. At the least, therefore, the new machines should help make studying more active and rigorous. At best, technology may free instructors from routine tasks so that they can give more time to the less formal kinds of teaching and counseling students value most.

There is likewise no reason to believe that computers will necessarily isolate students and reduce their contacts with one another. As previously mentioned, most uses of technology occur outside of class and serve to enrich the process of studying, which has traditionally been a solitary activity. At worst, technology may simply perpetuate that pattern, giving students opportunities to sit alone before their computer mastering programs instead of sitting alone reading an assigned text. But it is easy to design computer exercises that will actually increase student interaction. Computer games bring students together in teams. Pairs of students can readily cooperate in working through programs of computer-assisted instruction or trying to diagnose an ailment presented on videodisc. In short, technology need not separate students and can actually cause them to work together.

As Weizenbaum observes, a risk in using the new technology is that some students may become addicted and "exist only through and for computers." We must remember, however, that millions of young people arrive at college already familiar with computers. Many of them come equipped with their own models. As a result, there is little hope of preserving students from the danger of becoming obsessed with these machines

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whether or not universities integrate them into their teaching programs. All technology creates the possibility of abuse. One cannot reject computers on this account any more than one can give up cars because a minority will choose to drive too fast.

To many people, the greatest threat from the new technology is not the fear of isolation or addiction but the risk of undermining forms of knowledge and understanding that are not quantifiable or reducible to formal processes and rules. As one author puts it, "The issue is not whether the computer can be made to think like a human, but whether humans can and will take on the quality of digital computers."[9]

But technology need not force people to reason only in analytic or quantitative ways. For example, simulation can challenge students to speculate, to imagine new hypotheses and relationships, and to test their intuitions effortlessly. Used in this way, computers may provide one of the most intriguing tools yet devised to stimulate venturesome, creative thought. Already, tenth graders have actually discovered new theorems after having a chance to experiment with geometric forms through computer manipulations.

Even with more conventional applications, machines are unlikely to do much lasting damage to intellectual discourse in fields like literature and philosophy. Ingenious applications will be made in these subjects—some useful, some ludicrous—but the limits of technology should be obvious enough not to warp the main lines of scholarly inquiry and instruction. The greater risk arises in subjects, such as business management and public administration, where students learn to think about problems that involve a mix of different considerations including some quantifiable elements along with other values, possibilities, and risks that are intangible and not susceptible to precise measurement. Despite protestations to the contrary, some instructors will succumb to the seductive power of numbers, precision, and logical demonstration by neglecting the subtler aspects of human problems and caricaturing the world they seek to have their students understand.

Teachers can certainly use computers in ways that reflect these problems. For example, because ethical considerations are hard to incorporate in a program, they are simply left out of computer games that challenge business school students to act as if they were directing real corporations in a competitive environment. Because psychological and social elements are difficult to capture in programming simulated patients for medical schools, they are again omitted, thus reinforcing the tendency to ignore such factors and concentrate solely on the scientific aspects of disease.

Even so, there is little reason to believe that the clash between the humanistic and scientific approach to problems will be affected much by the uses we make of technology in education. Computers are only a recent arrival in a long series of efforts to emphasize the quantitative and verifiable in human inquiry. The struggle between what Pascal termed *l'esprit de geometrie* and *l'esprit de finesse* is an old struggle indeed. Computers may affect the debate but they are much more likely to do so through their applications to research than through their instructional uses. Modes of intellectual discourse on campus may be reinforced in the classroom but they are rarely decided there. Instead, their popularity depends on norms of scholarly research derived from judgments imposed by the disciplines through peer review, refereed journals, and faculty appointments proceedings. University authorities have as much chance of affecting this process as King Canute had of stopping the waves from mounting the beach.

These concerns by no means exhaust the problems that technology will create as it continues to evolve. Few universities have had to think about what they will do if students and faculty begin to read books by computer instead of checking out volumes in the traditional way. Will they dispose of their collections? Or place them in remote storage? Most institutions have not yet decided how to distribute the royalties from educational software. Will they be treated like textbooks, where authors keep all the royalties, or like patents, where universities and their scientists share the spoils? Networking could create problems of a different sort if students begin to pepper their professors with questions they are too shy to ask in person. Although such queries may tell instructors much about the difficulties and misunderstandings experienced by their students, professors may eventually be unable to cope with all the questions that pop up on their television screens. Such problems can be multiplied many times over. On reflection, however, none of them seems more intractable than the difficulties that technological change has traditionally created for society.

Effects on Learning

A radically different set of criticisms comes from investigators who question whether technology truly enhances learning. Remember Professor Clark's assertion that "media are mere vehicles that deliver instruction but do not influence student achievement." What Clark must mean is that technology rarely gives instruction of a kind and power that cannot be duplicated by more conventional means. Thus, the questions and answers contained in most computer assisted instruction could also be provided, albeit in more awkward form, by a cleverly arranged workbook. The computer simulations that help develop diagnostic skills might be given by a live tutor who acted as a patient and responded to questions until students could make an accurate diagnosis. Expert systems, like MYCIN, could be duplicated by simply allowing a student to observe a real expert go about solving difficult problems. Much of what computer graphics and videodisca provide could be approximated in only slightly more cumbersome ways by the clever use of mock-ups, videotapes, and film strips. In principle, therefore, the new technology seems unique only in allowing students to address certain kinds of problems with greater depth and sophistication through its remarkable power to manipulate data.

If this were all that could be said for the new technology, one would wonder whether universities and their corporate patrons had lost their minds by spending scores of millions of dollars on such equipment. But there are other justifications to consider before we make a final reckoning.

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The faculty has its own reasons to avoid spending much time on investigating how well their students are progressing. Professors are busy people with many interests other than teaching that compete for their attention. The last thing they want are major studies to probe the effectiveness of instruction. Either the inquiries will fail to produce convincing results and simply waste time and money or they will call for significant changes in teaching methods that will require many hours of labor, quite possibly in the pursuit of some seductive theory that will eventually be discredited. Fortunately for the faculty, there is a plausible reason not to mount a large institutional effort to explore how student learning might be improved. Research on this subject is extremely complicated. The goals are generally in dispute, the methodology still quite primitive, the relevant variables numerous and hard to disentangle. Because of these difficulties, the results are often intuitively suspect or simply inconclusive. Under such conditions, one can readily find reasons not to devote much time and attention to work of this kind.

In contrast to this tradition of indifference, investigators have shown a remarkable interest in experimenting with technology to try to improve the learning process. There are good reasons to expect this interest to continue. Much of the current work has relevance for commercial products—computer hardware, videodiscs, word processors, and the like. Corporations see the possibility of burgeoning sales and are willing to invest large sums in research and development and to give attractive discounts to open up university markets. Professors, in turn, are impressed by the power of the computer and often proficient in its use through their research activities. Some of them, at least, can be tempted to try the new technology in an effort to improve their courses. Students, too, are coming into the university in increasing numbers knowing how to use the computer; four million young people possessing such experience will enroll by 1987. Many of them will expect instructors to employ computers in their courses and will press them to do so, just as our own law students have done in asking to work with professors to develop CAI programs to supplement courses in accounting, corporations, property, and other fields.

This growing interest may well turn out to be the greatest benefit to result from the new technology. As more people begin to use technology for educational purposes, they are bound to think more carefully about the best ways to help students absorb new knowledge and master new intellectual skills. One simply cannot produce good software for teaching without paying close attention to the details of how best to present the material to enhance learning and sustain student interest. This is not characteristic of traditional instruction. For most professors, lecturing requires much knowledge and a fair amount of organization but otherwise proceeds intuitively with little conscious thought about how students actually learn. The same is even true of many seminars and tutorials. The task of designing educational software, however, cannot go forward in this manner. Every step of the process must proceed with a careful eye to its effect on the student or the program will not work.

This is the critical difference that probably accounts for most of the gains in speed and effectiveness of learning often attributed to computer-assisted learning. It is not necessarily the machines that produce these gains. More likely, the improvements occur because of the increased time and thought that come into creating the program. Either way, students stand to benefit from the result.

Despite these bright prospects, success is not assured and will probably not occur without the active help of those in positions of academic leadership. For all the experiments and publicity, we still have little first-rate software. Most of the programs available today are basic drill-and-practice routines that resemble expensive electronic workbooks rather than the more imaginative examples described in this report. Small wonder, since good programs often require more than two hundred hours of preparation for a single hour of instruction. To surmount this barrier, university administrators will have to do much more than shower their campuses with expensive equipment. A more important step will be to persuade some of the best teachers on the faculty to take an active interest in the new technology and give them the funds and technical help they need to develop imaginative applications. As in all human enterprise, choosing the right participants will be crucial. By and large, the best teachers have thought most about how students learn and will attract the widest interest and command the greatest respect for the work they do in using technology in their courses. The greatest challenge for educators will be to find ways of persuading such teachers to develop a keen interest in lending their talents to this task.

Deans and other academic leaders will also need to take an active part in making sure that new experiments are carefully evaluated. After all, assertions about how much computers can do to improve critical thinking are assertions that rest on still unproven hypotheses. Hence, each new program deserves a careful review to try to determine whether it does in fact help students to learn more quickly, or reason better, or understand new material more thoroughly. There is also much more we need to know about the new technology. In what circumstances does it motivate students more than conventional instruction? Does CAI help some students more than others? Does the use of graphics and the chance to visualize and manipulate abstract phenomena increase comprehension? If expert systems do not reflect how an expert actually thinks, can they still help students learn to reason more effectively?

Although universities have never shown much interest in studying the learning process, they will have reasons to evaluate the new technology. Administrators will want some way of deciding whether they can justify the heavy expense of purchasing equipment and developing software. Curiosity should also lead professors to inquire into the results of their efforts to use computers. Skeptics may ask why the faculty should be any more interested than they have been up to now in trying to measure the effects of their teaching. Yet the psychological climate for conducting such evaluations should be much more promising than in the past. It is one thing to judge the effectiveness of computer-based instruction and quite another to inquire into more traditional methods of teaching. The first merely involves evaluating the effects of a machine; the second calls in question the value of the faculty members themselves. The first may simply result in canceling an order for new microcomputers; the second carries the more threatening prospect of either causing professors to feel ineffective or forcing them to consider radical changes in their methods of teaching. With ingenuity, then, and a modest use of funds, a determined administration may be able to evaluate the new technology and thus learn to use it with discrimination.

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In the end, therefore, with all the exaggerated claims and the media hype, we can still look upon the new technology with cautious enthusiasm. At the very least, universities should manage to use technology to engage students in a more active process of thinking and problem solving that will help them learn more effectively. At best, the new machines may also be a catalyst to hasten the development of new insights into human cognition and new ways of helping students learn.

In many ways, this last possibility is the most intriguing. It is embarrassing that professors, who spend so much time evaluating and criticizing other institutions, devote so little effort to finding ways to improve their own methods of instruction. The task is surely complex and results may be long in coming—but that is no more true of educational research than it is of many other fields of inquiry to which faculty members devote their energies. In view of the billions spent on higher education and its growing importance to modern society, there is an evident need to work systematically at its improvement. If technology can help in encouraging such an effort, that is reason enough to welcome its appearance.

Derek Bok
President

March 1985

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